Going beyond SAT with STEM Projects

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Observations

- Normal high-school math- and science-course content is constrained by
  - state standards
  - the desire for students to perform well on standardized tests
- STEM courses
  - target a more ambitious student population
  - have fewer constraints imposed upon them
- Enhancing established PLTW courses in pre-engineering can
  - introduce additional concepts beyond traditional math and physics courses
  - lead to the achievement of more rigorous PLTW-based goals, *AND*
  - can advance student preparation for advanced course content in math and physics

Presentation Outline

1. An overview of PoE
   - PLTW-defined goals
   - PoE-defined technologies
   - Opportunities for course enhancement
2. A specific example
   - The mouse-trap powered racecar
3. Results
   - Product performance
   - AP Physics C testing
4. Conclusion

Principles of Engineering
Over-Arching Goal

Develop 21st Century Life and Careers skills through project-based, group-learning activities

“Principles” of Engineering
Course Objectives

- Definition & history of engineering practice
  - Career opportunities
- Communication & documentation
  - Writing, presentation, CAD
- Design methodology
  - Structured approach to problem solving
- Planning & time management
  - Resource and skills optimization
- Results validation and verification
  - Product performance assessment

Principles of Engineering
PLTW-Prescribed Technologies

- The PoE curriculum includes a number of "technologies" upon which the lessons are built
- It is in conjunction with these technologies that we are able to apply cross-curricular knowledge & skills to the analyze complex interactions

PLTW Principles of Engineering Technologies

- Mechanical Systems & Strength of Materials
  - Newton's laws of motion
  - Vector algebra
  - Atomic theory of matter
- Fluid Systems
  - Thermodynamics & ideal gas laws
  - Pre-Calculus concepts (flow-rates and motion)
  - Statistical mechanics

Principles of Engineering
More Technologies

- Electrical Systems
  - Electromagnetism (motors, generators, etc.)
  - Pre-Calculus concepts (integration)
  - Vector field theory
- Control Systems
  - Sensors & feedback loops
  - Computer programming
  - Boolean algebra & logic

Principles of Engineering
Additional Topics

- Product Reliability
  - Failure rates & redundancy
  - Probability & statistical inference
- Engineering Ethics
  - Safety & responsibility
  - Responsibility & accountability

Realization of Enhancement Opportunities

- High-level enhancement
  - Presented as an “enrichment” lesson
  - Limited theoretical or technical depth
  - Appeals to only a fraction of the class
- Detailed enhancement implementation
  - Fit the enhancement into the project definition
  - Make attainment of the principles part of the formula for success
  - Expect wide-spread acceptance of the challenge
- Example: mousetrap powered race car

The Racecar Project*

Design and build a mousetrap-powered model car

February – March 2012

∗ This project was originally conceived by Ms. Jennifer Pulliam, Physics teacher at HTHS (ca. 2000)

Project Overview

- Three person teams
  - Teacher-assigned teams
  - Specific roles & responsibilities
- Two competitions
  - The fastest car (across 5 meters}
  - Furthest distance (2 minutes)
- Constraints
  - Time (including lessons on “theory”)
    - Approximately 5 weeks
  - Materials (“shop time” not needed)
    - Standard mousetrap

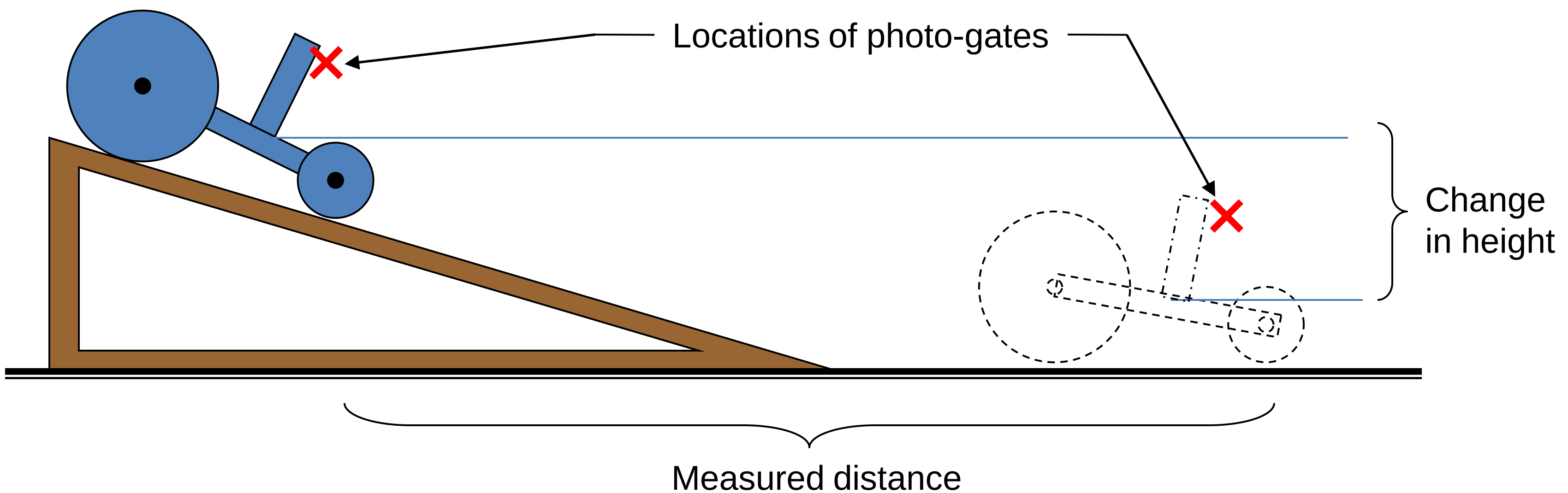
Key Assignments

- Project Manager (many things to schedule)
  - Decision matrix and race selection
  - Friction test
  - Qualifying run
- Chief Engineer (many calculations to perform)
  - Energy stored in the mousetrap
  - Theoretical speed or distance of the car
  - Corrections to predictions due to frictional losses
- Construction Engineer (much prototyping)
  - Implementation options
  - Construction planning & scheduling
  - Design optimization

Required Experiment on Energy Losses

To estimate race car performance

- Determine change in gravitational potential energy
- Calculate theoretical final speed
- **Measure actual final speed**
- Determine energy losses per meter of travel
- Determine the energy available in the mousetrap
- Estimate average speed or ultimate distance of travel for the contest

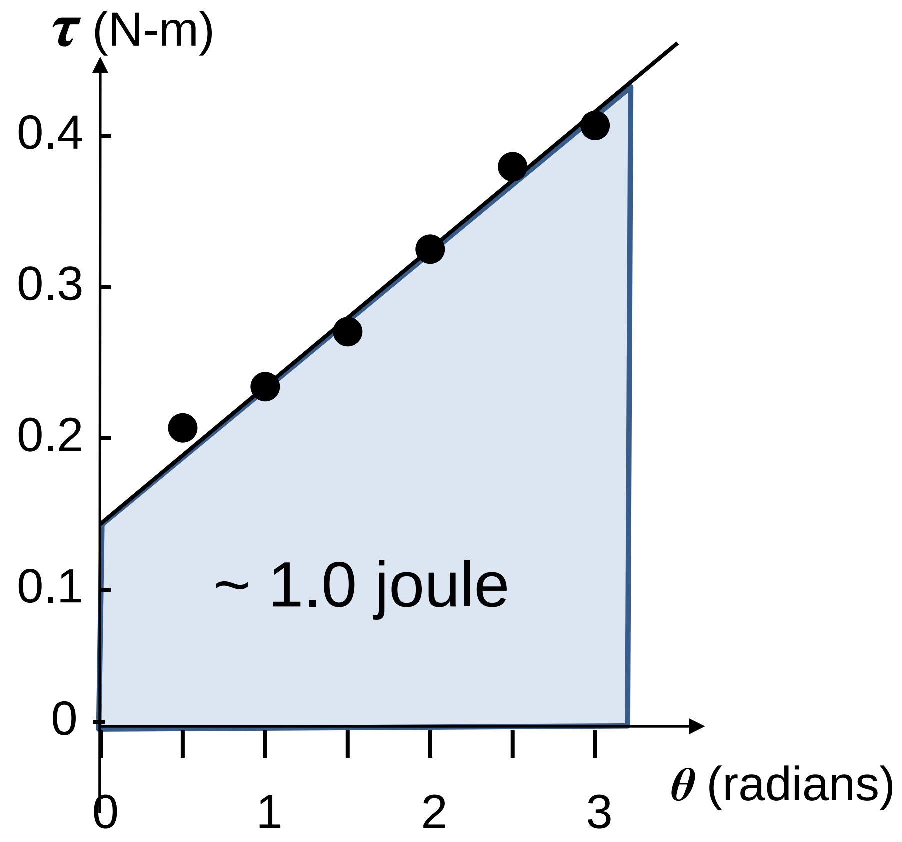


Where is the "Enhancement"?

- Total kinetic energy of the moving race car
  - Translational kinetic energy ($\frac{1}{2}mv^2$)
  - Rotational kinetic energy ($\frac{1}{2}I\omega^2$)
  - "Rolling without slipping" relationship
- Energy stored in the mousetrap
  - Torsion spring action
  - Potential energy = torque times angle of rotation

The Energy Stored in a Mousetrap

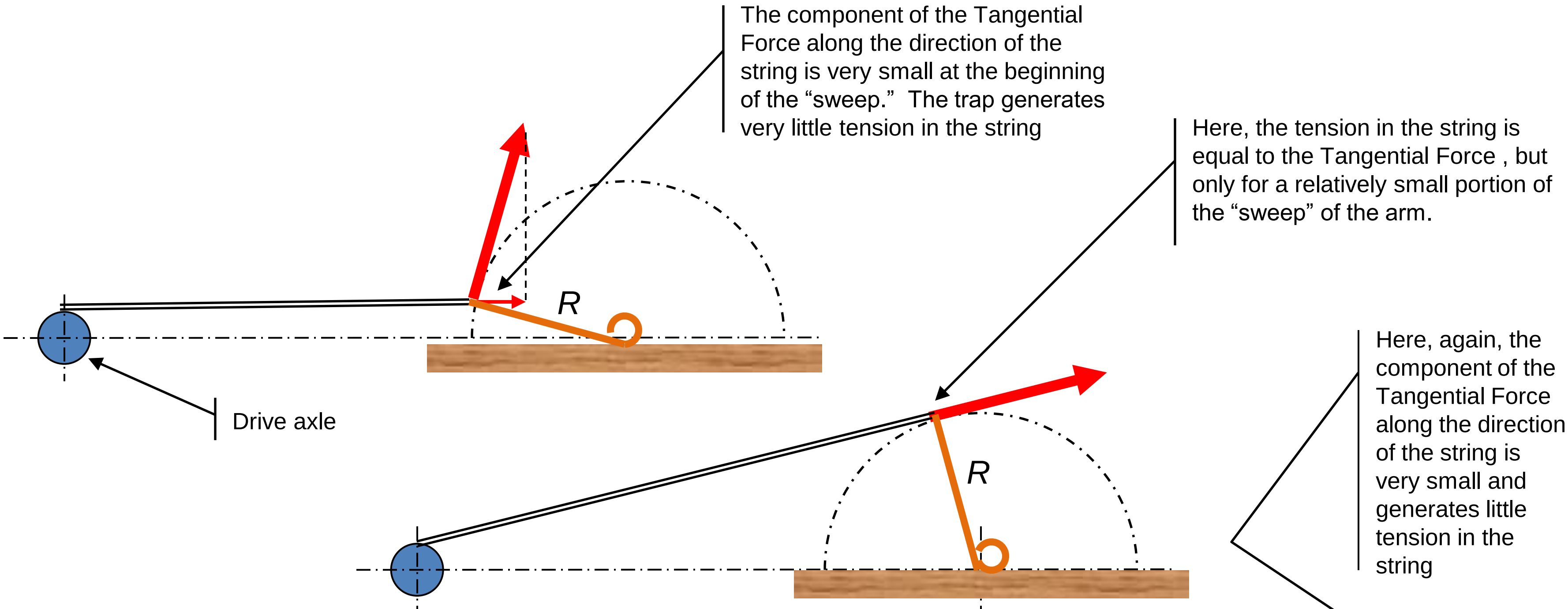
1. Students measure the amount of force need to hold the clapper at a specific angle. They multiply that force times the length of the clapper.
2. The slope of the torque vs. angle is the torsional "spring constant."
3. The area under the line is the energy stored in the spring.

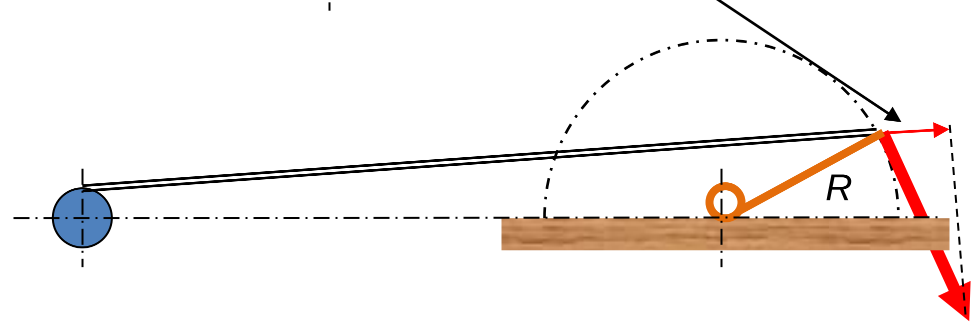


Additional Design Considerations

- Efficient extraction of energy from the mousetrap
  - Use the high-power part of the cycle
    - Achieve maximum acceleration of the car, BUT
    - Avoid having the wheels spin on the floor
  - Design a method to utilize energy all along the cycle

Extracting Energy from a Mouse Trap





<u>Just wrapping a string around the drive axle</u> and tying it to the "clapper" of the mousetrap only makes effective use of about half the "sweep" of the clapper arm.

Moreover, it only unwinds a length of string equal to 2R.

Additional Design Considerations

Optimize the power usage profile

- Short Race
  - Use all the energy during the first part of the race
  - Coast at relatively high speed to the finish line
- Long Race
  - Build momentum at the beginning of the race, BUT
  - Save enough energy to overcome irregularities in the path

What Students Take Away

- Concepts in rotational dynamics
  - The relationship between torque and angular momentum
  - The relationship between angular momentum and rotational kinetic energy
- The interplay between rotational dynamics and linear dynamics
  - Rolling without slipping
  - The role of design in optimizing race car performance

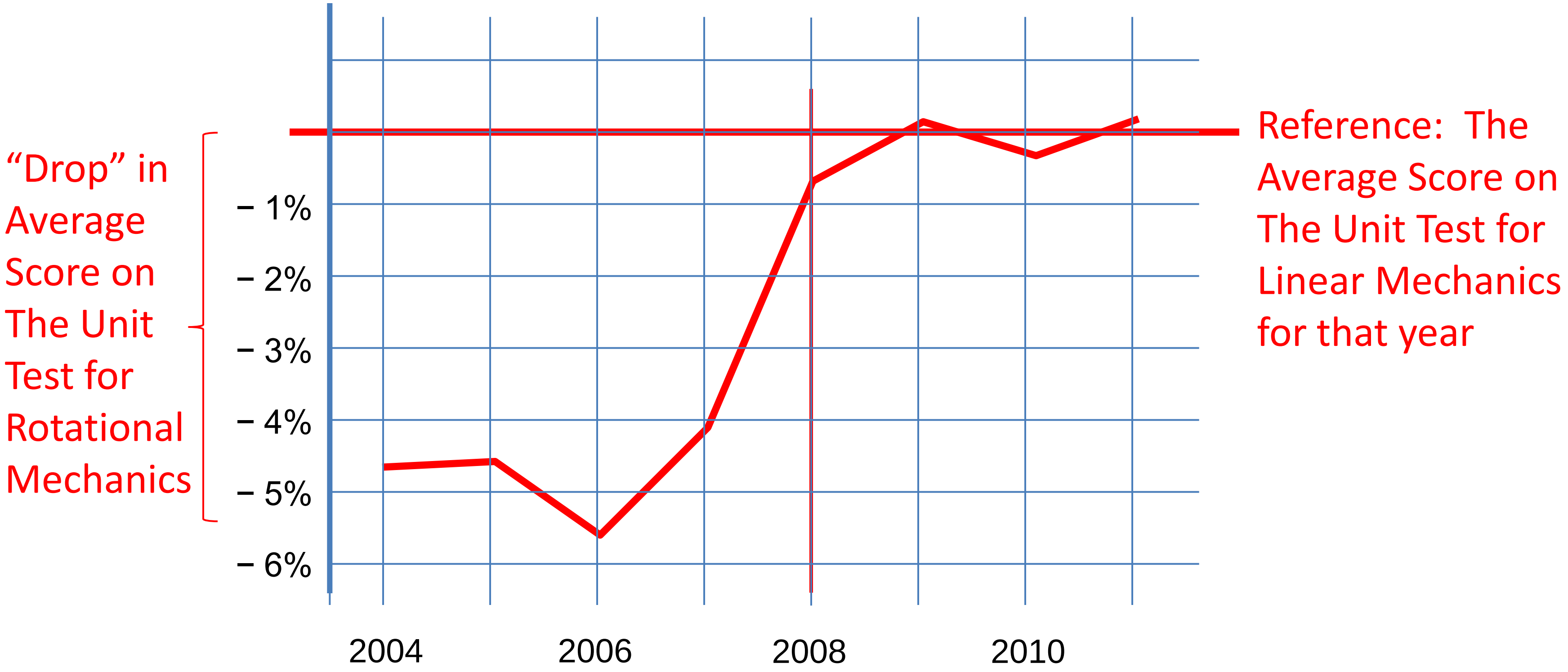
So What?

- Students are better prepared physics than their peers in traditional physics classes for “advanced”
  - The SAT Subject Test in Physics does not test rotational dynamics (torque, angular acceleration & momentum)
  - A typical high-school course in physics would not emphasize these relationships.

So What?

- Our experience is that students are able to apply this knowledge to their AP Physics course
  - Less of a “shock” factor when the course transitions to rotational dynamics (Smoother learning transition from linear to rotational mechanics)
  - More time to focus on rotating systems which require the application of calculus
  - Better performance on AP exams in the spring.

AP Physics C Scores Improvement



The "drop" in test scores that previously occurred when the course moved from "linear" to "rotational" mechanics virtually disappeared once we added more rotational mechanics to lab physics and required an analysis of the racecar to be part of the PoE design documentation.

Conclusion

To better prepare students for “advanced” STEM courses:

- Teachers can enhance technology courses for which there are fewer national standards and exit exams in place
- Students can explore complex math and physics relationships within the context of a hands-on project where they can get immediate feedback on the success or failure of their assumptions

Conclusion

These experiences can improve the acquisition of new, required skills when the students encounter them for a “second” time, in advanced coursework.

Students exposed to this kind of curricular enrichment will meet future challenges at a level above their peers, in college and beyond.